ORIGINAL CONTAINS COLOR ILLUSTRATIONS

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1. Introduction

Progress on the project entitled "AUTOMATION OF REPLICATOR DATA ANALYSIS" is described in this report. The goal of this project is to automate analysis of formvar replicator data using digital image analysis and computer control of film advance. The formvar replicator data supplies number concentrations and habit information for ice crystals and cloud droplets simultaneously (5 μm < D < 200 μm, where D is particle maximum dimension) in cirrus and mixed phase clouds. Crystal replica can be imaged at much higher resolution than with other optical probes such as the Particle Measuring System 2DC probes.

Our software and hardware goals described in the original proposal have been fulfilled. We are now beginning to analyze data with the system, and are in the process of working out minor software corrections.

2. PROGRESS

Most of the hardware and software was in place at the time of our last progress report. The course of action we pursued since our last progress report to finish development of the replicator data analysis system was as follows:

a. Finish the stepper motor control of film advance.

b. Place film advance and frame counting entirely under computer control with use of the National Instruments Lab View program and the CONCEPT VI GTFS frame grabber I/O driver.

c. Measure particle properties (size, projected area) with the CONCEPT VI software.

d. Use the Lab View software to keep track of aircraft data, and to compute particle number and area distributions.

A new atmospheric science graduate student, Mark Turner, joined our group in the summer of 1994, and has been largely responsible for software development, working under our guidance. We have been busy integrating each of the system components into an overall analysis strategy that is easy for the user to implement, is accurate, and is the best tradeoff between analysis time and spatial resolution (both in cloud resolution and video image resolution).

3. Description of automated system for replicator data analysis

a. Hardware

Figure 1 is a video photograph of the system for automated analysis of replicator data, except for the computer. Replicator data to be analyzed is placed in the reel on the right of the figure. A stepper motor and slip clutch (not shown) would rotate the data supply reel in a clockwise sense when the clutch is not slipping; otherwise, this stepper motor only supplies tension to the replicator film. Movement of the replicator film (either toward or away from the data supply) is controlled by the film transport. The computer interface for the film transport is barely visible behind the microscope. Replicator film is imaged, possibly under a variety of magnifications, using the microscope and video camera. The fiber optic illuminator for the microscope is shown in the rear. The replicator data take up reel is also equipped with a stepper motor and slip clutch to keep the film tight. The joystick controls for microscope y axis position and focus is on the left.

Figure 2 shows the user station for analyzing replicator data. The video monitor is useful for focusing the microscope while the computer is busy printing or writing data to disk. The user interacts with the system by input through the keyboard, computer mouse, and the proportional (the farther you push, the faster the motors run) joysticks for focus and y axis position control. The computer with frame grabber, and the printer, are not shown, and are on the lower shelf of the table. In routine operation the user can control all aspects of the system hardware shown in Fig. 1 using the computer and the joystick controls.

Figure 3 shows the film transport system in more detail than in Fig. 1. The stepper motors are interfaced to the computer through the stepper motor control box. The frame grabber on the computer has both a bnc connector for video input and 4 lines of digital output for stepper motor position control. The replicator supply reel is equipped with a stepper motor and slip clutch to keep the film under tension. Figure 4 shows a more detailed view of the film transport. The film is threaded through the lower idler arms, and over a fixed radius roller equipped with extended nubs that push through the film sprocket holes. It is vital to note that each stepper motor pulse moves the film a fixed, known distance, so that one may convert film position in meters to aircraft position in cloud. Data from the aircraft position is loaded into the software for performing this conversion.

Figure 5 shows the detailed microscope arrangment. The specifications for each lens, and for the pms 2dc probe used on the University of North Dakota Citation aircraft are as follows:

Objective	Resolution (pixels/μm)	Field of View (μmxμm)	Working Distance (cm)
1x	0.1745	3667x2750	12.9
2x	0.3265	1960x1470	5.4
3.5x	0.5647	1133x850	2.4
5x	0.9600	667x500	1.7
PMS 2DC	0.0303	1056x1056	n/a

The reciprocal of resolution is the number of microns spanned per pixel in the image, where the frame grabber digitizes images with 640x480 pixels per picture. For example, the 1x objective should barely resolve a crystal with ≈ 6 μm diameter, and the 5x objective should barely resolve a crystal with ≈ 1 μm diameter. As resolution increases, the field of view (actual area of the replicator film viewed) decreases. Large field of view is desirable to minimize analysis time. We usually use the 2x objective since it gives a reasonable trade-off of large field of view for lower resolution. Note that the 2x objective gives us a better field of view than the PMS 2DC probe, and about ten times the resolution.

Denote by; N = number of crystals per liter in the cloud (the desired quantity) n = number of crystals per area in the microscope field of view (the measured quantity); f_s =

replicator film speed during data acquisition, a_s = aircraft speed during acquisition, and w = replicator slit width parallel to the direction of travel of the replicator film. Typical values are f_s = 7.62 cm/sec, a_s = 110 m/s, and w = 2.5 mm. Then

$$N = n\, f_s / (a_s\, w) \quad , \tag{1}$$

is the number of crystal per liter in the cloud. For example, if there is one crystal in the field of view of the 2x objective, and we use the typical values, then N ≈ 96 crystals / Li. Typical values of N are N ≈ 100 to 500 / Li for crystals less than 25 µm, so we might expect 1 to 5 crystals per field of view using the 2x objective. The spatial resolution of the replicator data (in the cloud) is denoted by S_r and is given by

$$S_r = a_s\, w / f_s \quad . \tag{2}$$

The range of S_r is thus S_r ≈ (0.9 m to 7.2 m). Only the 1x objective has a field of view along x greater than w. Thus for all other objectives, the spatial resolution of changes in cirrus cloud properties as measured by the replicator, and analyzed by the automated system, is given by Eq. (2). Note that since the spatial resolution of the film transport stepper motor is 304.6 µm per step, the stepper motor resolution does not hinder the overall spatial resolution of the system.

Figure 6 shows the proportional joystick control box for adjusting film y position and microscope focus. Cables from this box are connected to DC motors on the microscope to perform focusing and y axis position adjustment. Left-right motion of the joysticks moves the microscope stage in-out, and up-down. The farther the joystick is pushed from equilibrium, the faster the DC motors turn.

b. Software and system operation

Film advance and frame counting are entirely under computer control with use of the National Instruments Lab View program and the CONCEPT VI GTFS frame grabber I/O driver. Data files supplying time resolved replicator tape count, aircraft speed, altitude, latitude, longitude, and air temperature are read by the Lab View program, and are used, in part, to compute the replicator sample volume.

The National Instruments LAB VIEW programming environment is used for controlling all aspects of the automated replicator analysis system. This programming language is largely symbolic, with Virtual Instruments (VI's) that are connected by wires. VI's are like traditional subroutines used by languages such as FORTRAN, and wires are analogous to variables passed between subroutines. The programmer obtains an immediate appreciation of program flow when viewing the wiring diagram. The CONCEPT VI GTSF software contains the driver for the SCION framegrabber card, and also performs digital image analysis. The user of LAB VIEW VI's operates a software instrument with buttons, toggles, graphs, switches, etc, that performs the intended function. The front panel of the automated replicator system is shown in Figure 7.

Operation of the Virtual Instrument is a sequential process with six major steps. Controls of the various sub-systems of the automated replicator analyzer have been grouped together on the Front Panel and color coded for ease of use. As the user and VI interact during data analysis indicator boxes activate when the VI requires user input. Refer to Figure 7 during the following discussion.

Step 1: Preliminary Controls (Bright Green)

These Controls set the fundamental input parameters to the system. Objective choice determines video resolution; Results are displayed in Brown indicators below. Aircraft File Name and Path controls choose which data is to be analyzed.

Step 2: Motor Controls (Yellow)

Choice of Single Video Frame or Time positioning is the main use of this set. The user inputs a Time in hours-minutes-seconds (H.M.S.) corresponding to aircraft time. The film will be advanced to that location and analysis may begin. After analyzing one Video Frame the user may then input a new time or, more likely, select Single Frame and move one video screen full further in the film. Numeric indicators show Time and Steps of the present film location. Initialize Step is used to force the step count to become Initial Step.

Step 3: Image Modification Controls (Light Blue)

Once the film has arrived at the desired location digital image analysis may begin. These controls first grab the image from the camera and display the base picture on the computer screen. Then the image thresholding is performed, according to the limits specified by the slider scale. Any pixel value between the bounds is turned to white (pixel value =255) while all others are turned black (pixel value = 0). This leaves the image with speckle and particles. Next the image is passed through an erosion process to destroy the small speckle and leave only particles. The resultant count of particles is displayed.

Step 4: Particle Selection Controls (Blue)

After initial image processing the image will contain particles that may or may not be actual ice crystals. Further elimination of bad particles may be placed by user choice of Upper and Lower size limits in micrometers. The number of surviving potential crystals is displayed. Here also are the controls for the binning of crystal size data. The user must select both the number and width (in micrometers) of the bins. Binning takes place automatically as the crystals are chosen in the next section.

Step 5: Crystal Controls (Light Green)

After all image processing and limits have been placed upon the particles each potential crystal is displayed on the computer screen. The particle number, area (µm^2), and size (µm) are shown on the VI's front panel. The user chooses yes or no for the currently displayed crystal to keep or discard it.

Step 6: Printing Controls (Purple)

Here the user may elect to print the Video Frame image currently being analyzed.

Step 7: Column Controls (Orange)

When one video frame has been processed and its crystals extracted and binned, the user may continue with the present column of video frames (corresponding to a specific time in the flight) or move to a new column (a new time). The current Frame and Column numbers are displayed.

Step 8: Try and Focus Controls (Red)

If the user chooses to analyze another frame in the same column the try must be moved in or out (Y Axis desk lever) and the focus may need to be fine adjusted (Z Axis desk lever).

Step 9: Column Data Controls (Pink)

As the program proceeds data generated for the column is saved to the directory specified by Base Path for Column Data with the name of the flight as the filename. The data is stored as tab separated strings with end of line character per column. The stored values are: Time(s), Position(m), Sample Volume(L), Time(H.M.S.), Altitude(km), Temperature(C), Latitude(deg),Longitude(deg),Area of Video Frame(μm^2),Bin Size(μm), Number of Bins[n], Bin Data for Bin n,..., Number of Crystals[i], Diameter of Crystal i(μm), Area of Crystal i(μm^2),...

Step 10: Program Controls (Brown)

The user can choose to end analysis or continue with another column of video frames.

Results of analysis are presented in the large lower indicator. It is composed of several levels of data. Lab View has data structures called clusters that may contain radically different types of data under the same label. After analysis of several columns the program forms an Array of Columns (the outer red box). Each Column Data Structure (orange box) is a cluster of the Number per Liter for Column (cluster of small blue boxes) and an Array of Frames (purple box). This array contains all the frames analyzed for the column and is itself a cluster. Each Frame Data Structure (brown box) is composed of the Name (bright green), Bin Data (blue boxes), Air Data (yellow box), Image (red box), and an Array of Crystals (green box). The Crystal Data Structure is composed of the Name (bright green), Global Rectangle pixel coordinates in the image (brown), Area and Size (blue).

c. System specifications

1. RECENT REFERENCE FROM FIRE II ANALYSIS: W. Patrick Arnott, Ya Yi Dong, John Hallett, and Michael R. Poellot, 1994: Role of small ice crystals in radiative properties of cirrus: A case study, FIRE II, November 22, 1991. J. Geophysical Research vol99, noD, pages1371-1381. This reference describes the type of analysis we can perform, though results reported therein were not obtained with automated system.

2. REPLICATOR DATA: Replicator data is collected on 16 mm film by coating the film with formvar and exposing it to the airstream from either an aircraft window, or from a wing. Particles smaller than 10 μm can be routinely and reliably identified with use of microscopy. Replicator derived size distributions are vital for crystals with maximum dimension in the size range 10 μm < D < 200 μm, where PMS data is either totally lacking, or of poor resolution. PMS data is often sufficient for deriving size and projected area distributions for particles larger than 200 μm, but is often not sufficient for crystal habit identification. Though replicator data yields size distributions for particles larger than 200 μm, the chief advantage of the data for larger particles is in the fine detail that can be achieved for identifying crystal habit and assessing when aggregation has occurred. Replicator film speeds per second: 1.5", 3.0", 4.5" ... 12.0".

3. IMAGE DIGITIZATION: 640*480 pixel resolution frame grabber card.

4. RESOLUTION: 0.3265 pixels/μm resolution nominal, though adjustable through use of other microscope objectives. (Compare: The PMS probe flown on the CITATION has only 0.0303 pixels/μm resolution.)

5. FIELD OF VIEW: 1960 μm x 1470 μm nominal, though adjustable through use of other objectives. (Compare: The PMS probe flown on the CITATION has 1056 μm x 1056 μm field of view.)

6. MOTORIZED CONTROL OF FILM POSITION: Frame grabber card has digital I/O that is used for stepper motor control for accurately determining position on the replicator film. Position on film is translated to aircraft time by use of aircraft state data and interpolation. Stepper motors control position along the film length, and DC motors control both the microscope y-axis position and focus so the user can effectively

analyze data without having to physically get up and tweak the microscope. Stepper motor advances the film 304.6 μm per step.

7. DIGITAL IMAGE ANALYSIS: Digital image analysis is used to measure crystal maximum dimension and projected area. Each crystal must be accepted/declined by one click of the mouse so that the element of human decision makes the final choice on which crystals are counted.

8. NOMINAL SIZE BINS: Size bins are 0-25 um, 25-50 um, ..., 475-500 um. The number per liter in each bin is counted, along with the projected area of each crystal. Number and dimensions of size bins are user selectable.

9. HARDCOPY OF CRYSTAL IMAGES: Individual crystal images can be saved or discarded, and can be printed along with a scale indicating size, and with the pertinent aircraft state data - lat, long, air temp, height, and aircraft time.

10. FURTHER PROCESSING OF PMS AND REPLICATOR DATA AVAILABLE: We can also estimate crystal mass by use of mass dimension relations once crystal habit has been identified from replicator data. Mass dimension relations will also be derived using cloud scope data. Also available are: Total concentration in #/Liter, and the mean crystal diameter as a function of time. Total projected crystal area / Liter, (useful in computing extinction and other radiative properties).

4. Plans

The hardware and software is now in place. The course of action is to make sure the system is functioning properly by:

a. Analyzing data to make sure system operation flows smoothly,

b. Analyze data from 5 Dec 91, second flight, and compare with FSSP results of Mike Poellot from the University of North Dakota,

c. Compare automated analysis with hand analysis of 22 Nov. 91 data.

The main product of our efforts is characterization of cirrus clouds from the view point of small crystals (<200 μm) and their radiative and microphysical significance. We plan to undergo a number of case studies involving data from FIRE, TOGA-COARE, and other cirrus field studies; to find out where small ice crystals are prevalent; to determine their numbers, sizes, crystalline forms, and growth environments; and to assess the accuracy of PMS probes for measuring cirrus properties. We often observe bimodal size spectra, though do not yet completely understand the mechanism(s) of their existence.

FIGURES

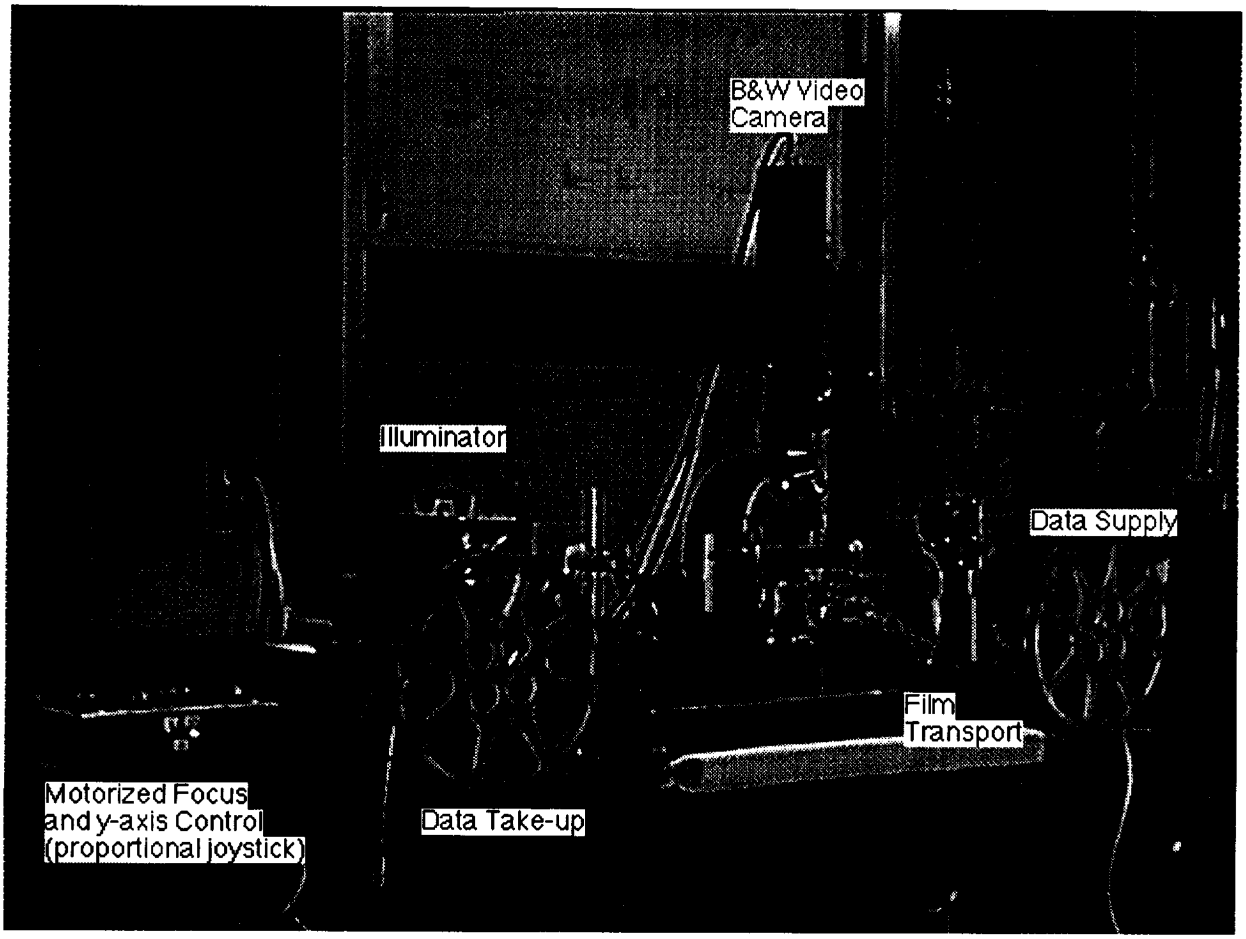

Figure 1. Overall view of the system hardware, except for the computer.

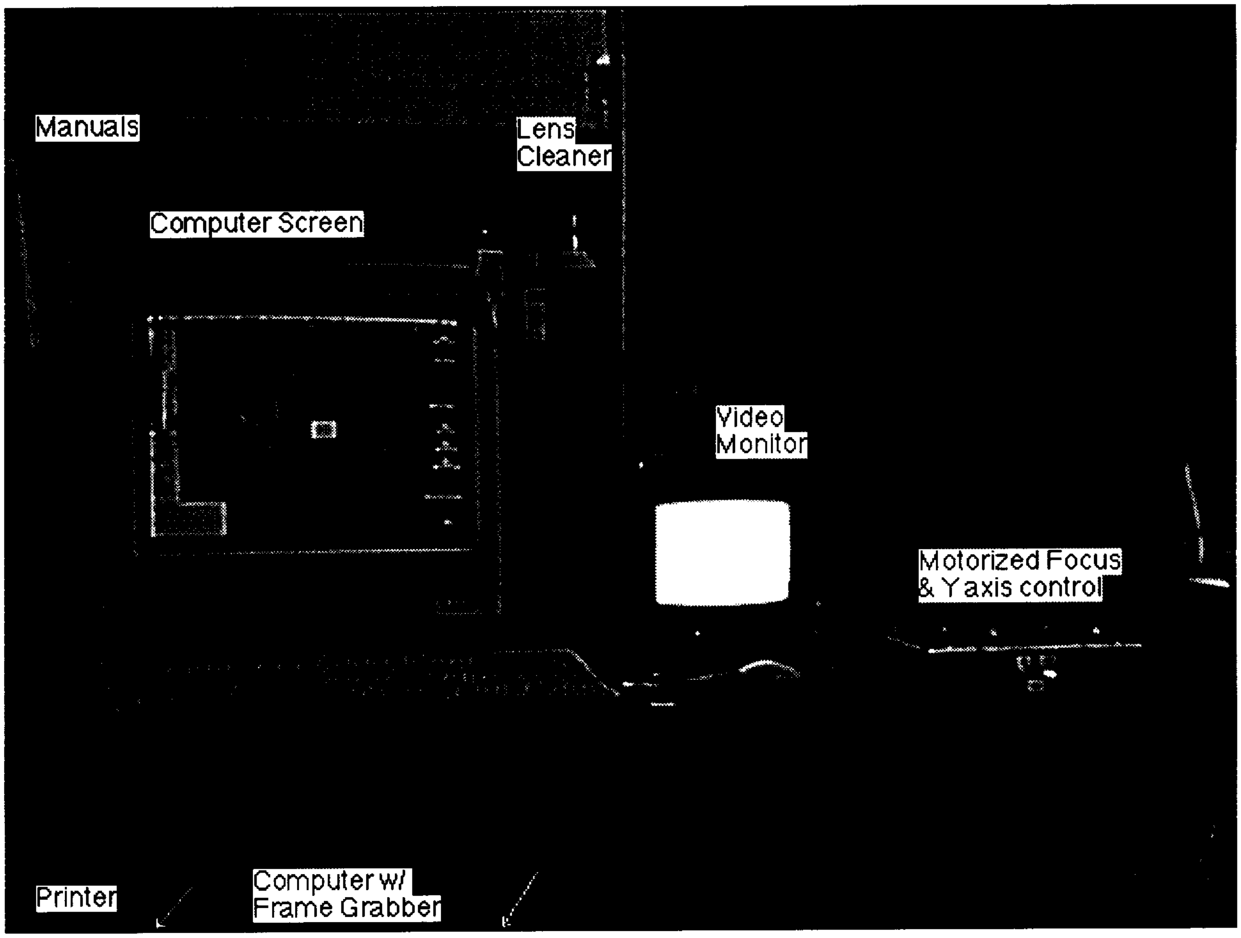

Figure 2. Overall view of the computer arrangement. Note that user input to the replicator analysis system occurs through the keyboard, mouse, and proportional joysticks for focusing and y axis control.

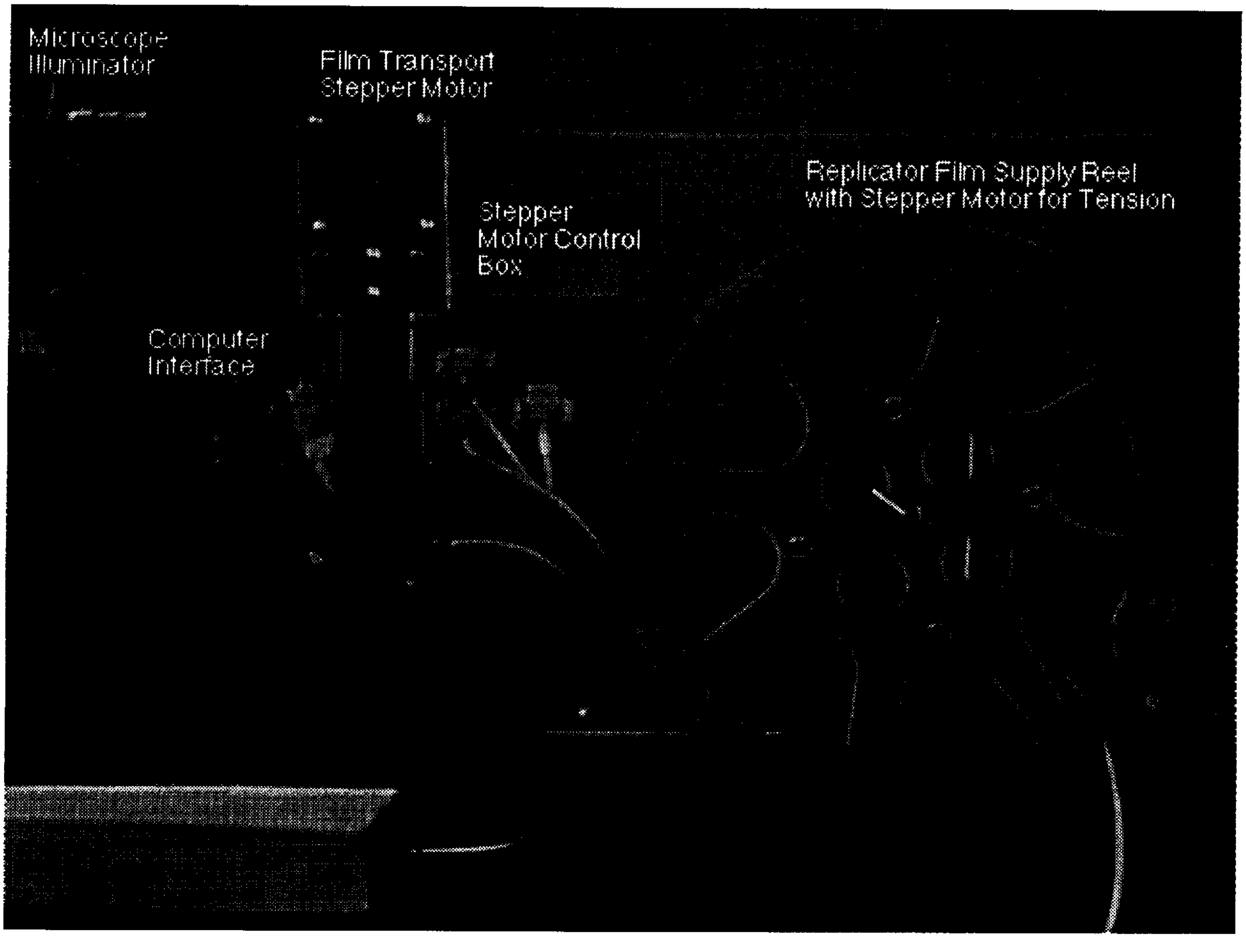

Figure 3. More detailed view of the film transport.

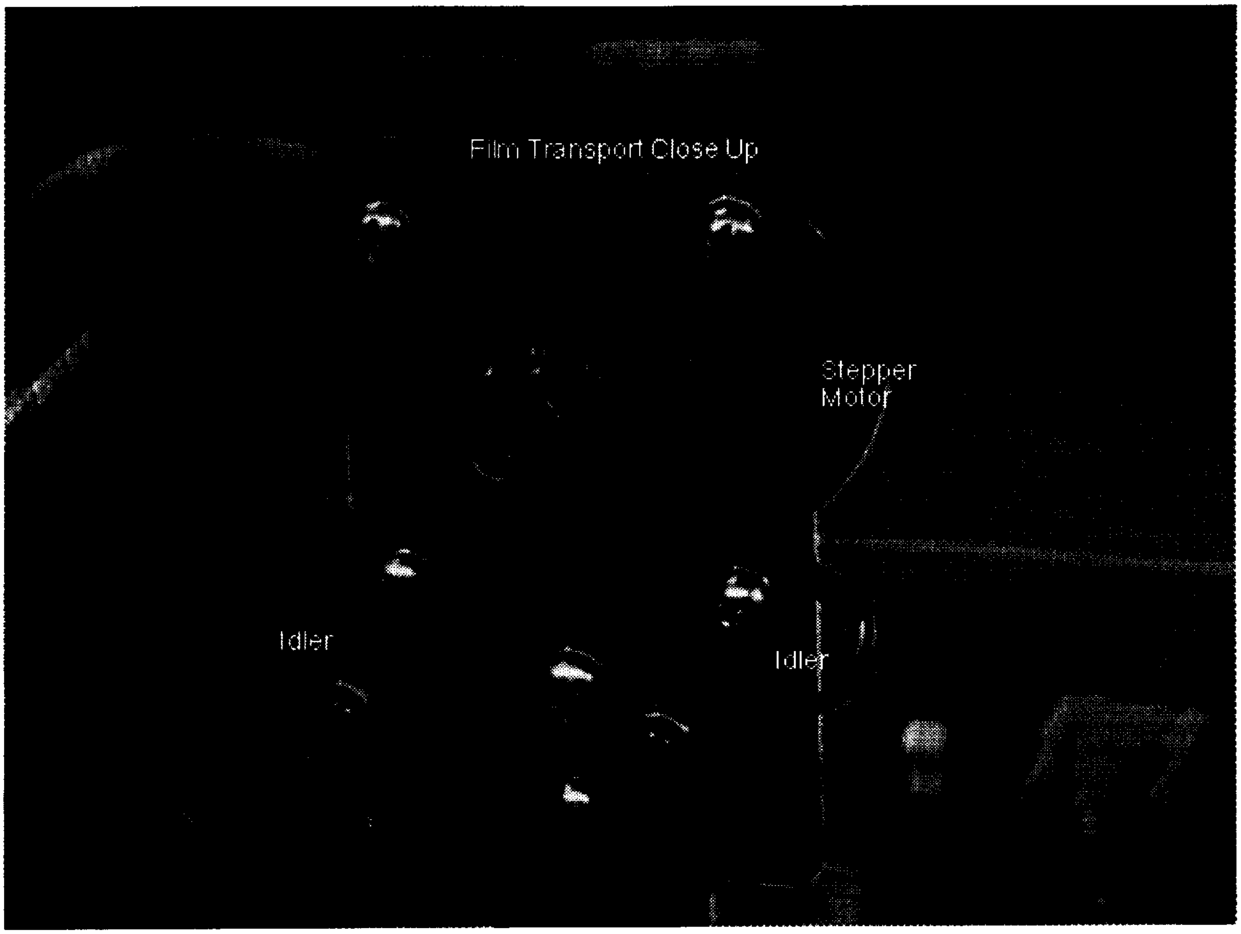

Figure 4. Detailed view of the film transport. A stepper motor is mounted on the reverse side.

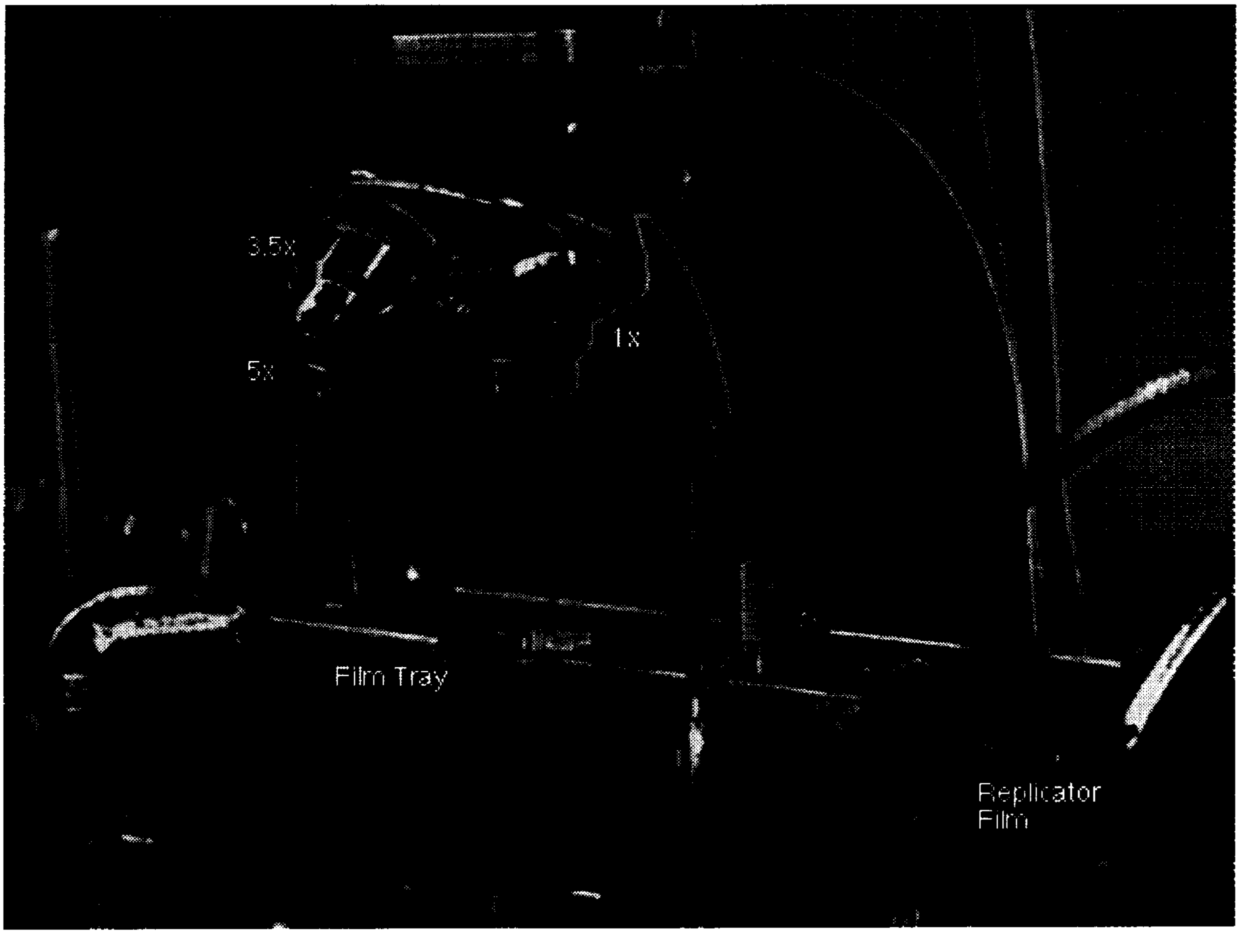

Figure 5. Detailed view of the microscope. Film is transported along the x direction by the stepper motor shown in figure 4. Film motion perpendicular to x is controlled using one of the joysticks in figure 6 and a DC motor mounted under the microscope stage. Focus is achieved using the other joystick in figure 6 and a DC motor mounted on the microscope body.

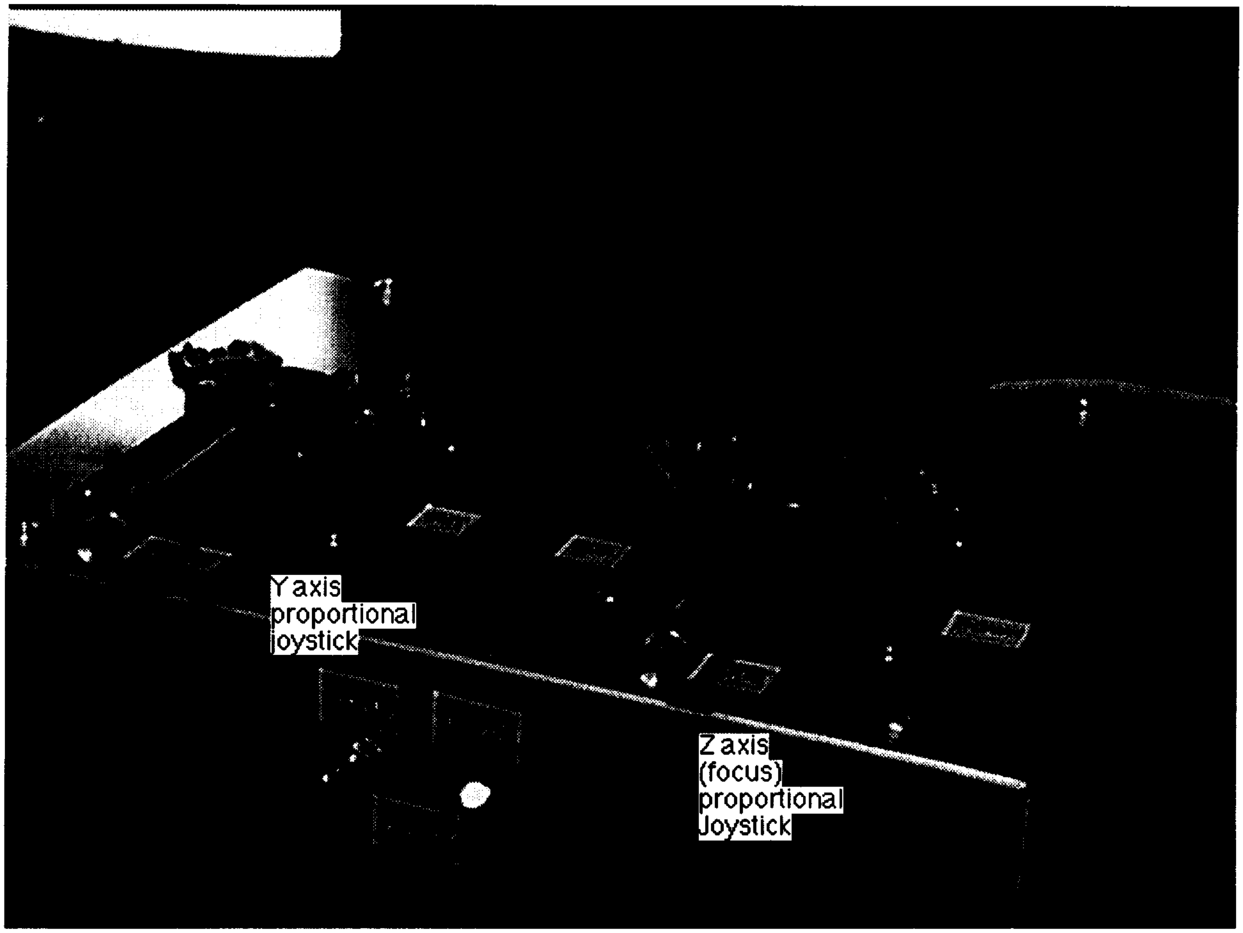

Figure 6. Joysticks used to focus the microscope and to control the y position of the replicator film.

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Front Panel

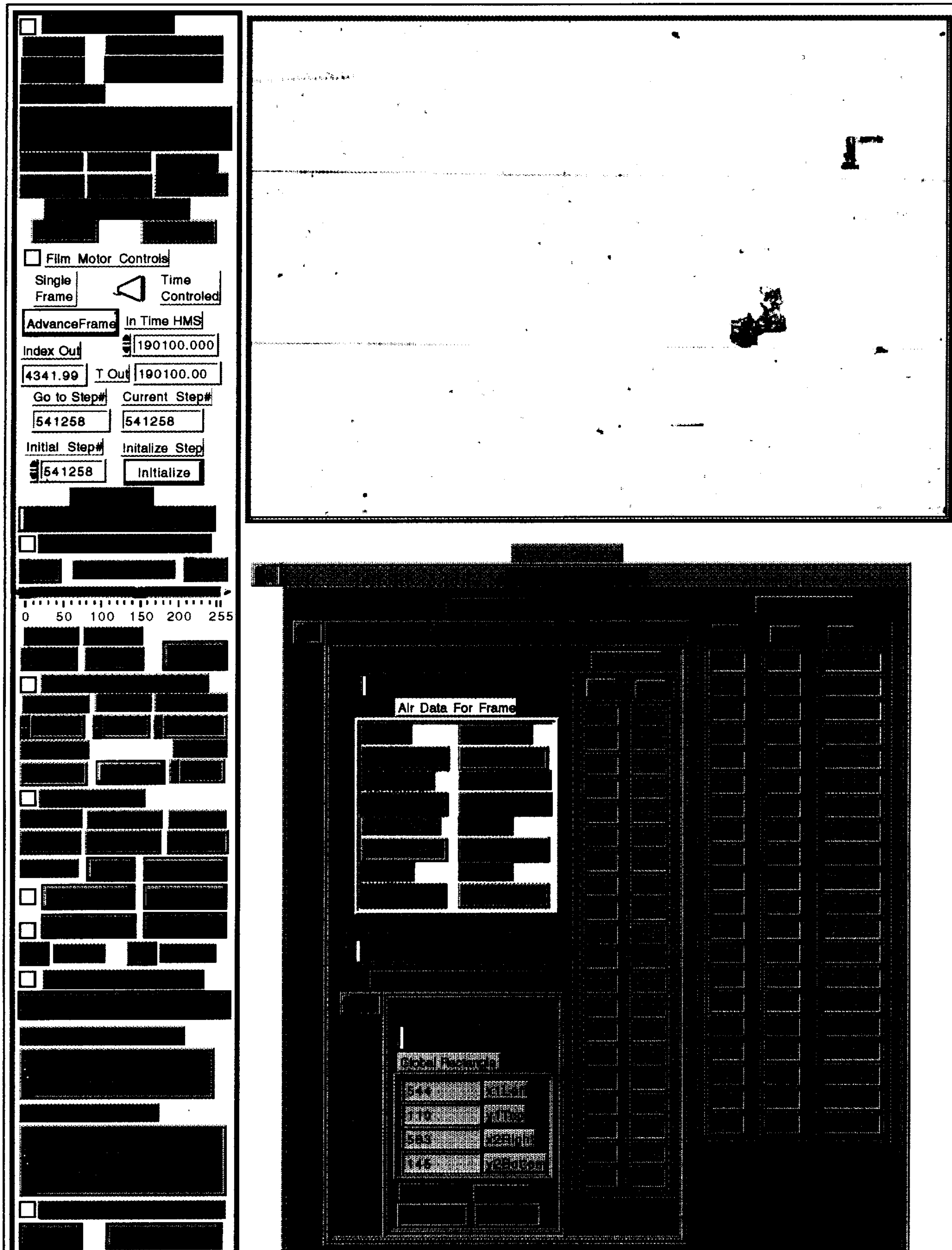

Figure 7. Front Panel of Virtual Instrument (VI) Used in Digital Image Analysis and Crystal Data Collection of Replicator Data.